A Robust Spatial Acquisition Algorithm for Extended Source using Subpixel Image Scanning

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Summary

Extended source spatial acquisition is a critical technology for deep space optical communications. A new image processing algorithm based on sequential Earth images has been proposed. The new algorithm is not only more accurate but also less sensitive to the noise. Robustness of the algorithm has been demonstrated through theoretical analysis and simulations using various Earth images.

Abstract

NASA/JPL has initiated a technology development program to explore laser communications for deep space applications. The purpose is to increase the information return capability by at least an order of magnitude while reducing the size of the spacecraft. The inherent advantages of laser communication over traditional RF communications lie on the fact that shorter operating wavelength requires significantly smaller aperture. For spaceborne systems, this translates to smaller beam divergence and hence the reduction in size and mass of the communication system. The overall system cost could also be reduced by a significant margin while maintaining similar or greater data return capability.

One of the several technical challenges that could hinder the development of laser communications is that the smaller transmit beamwidth imposes stringent demands on the pointing accuracy of the instrument. Inaccurate beam pointing can result in significant signal fades at the receiving site and a severely degraded system performance. As a result, the laser transmitter on board the spacecraft must be capable of tracking the receiving station to maintain small residual pointing error compared with the transmit beamwidth. For deep space applications this requires pointing the transmit laser beam to within 1/20th to 1/30th pixel accuracy based on the proposed 1024 by 1024 focal plane array (FPA). Furthermore at distances exceeding 1 AU (astronomical unit) from the Earth, a tracking method based on the Sun-illuminated Earth images has been favored over an active laser beacon tracking primarily due to large laser power required. To successfully track a Sun-lit Earth image, an accurate spatial

acquisition must be preceded to provide conversion from tracking output to actual transceiver locations.

Two algorithms based on single snapshot of Earth image have been investigated for acquisition using image correlation and edge extraction. Both algorithms produce satisfactory results when the Earth albedo remains relatively stationary. However, errors on the order of $1/10^{th}$ of the pixel width have been recorded in the presence of mild albedo variations which are typical for most communication scenarios. This exceeds the current error budget of smaller than $1/20^{th}$ pixel width for the initial spatial acquisition.

This paper describes an alternative scheme to meet the pointing requirement based on sequential image scanning in orthogonal directions. The images will be taken with step sizes smaller than a pixel size. This can be accomplished using the state-of-art Fine Steering Mirror which has a very fine resolution even at high speed. The step size and algorithm complexity will determine the magnitude of error. The scanned image sequences represent the image intensity profiles convolved with the point spread function (PSF) and window averaging. As the step size becomes smaller, the intensity profile becomes closer to the true image intensity profile. This comprises more information than one snapshot of the image, thus produces better computational accuracy.

The algorithm represents an extension of the edge extraction scheme, which uses the second derivative rather than a non-zero threshold value to determine the center of the Earth. In general the algorithm searches for the first location of the second derivative when it becomes zero from boundary of the images. Using tangential lines at the inflection points, the relative edge points that are unique and independent of the magnitude of the boundary (edge) intensities can be determined. This approach is also less sensitive to the albedo changes. The only requirement is the local uniformity in the intensity distributions near the edges. Once the edge points can be determined at one direction, the procedure can be applied to the orthogonal direction.

Simulations using real Earth images with different phases showed that the error is generally less than $1/30^{th}$ pixel width given the step size of $1/20^{th}$ pixel width. The test conditions using an average signal to noise ratio (SNR) of 100 where SNR = power of image/noise power. The error can be reduced further with smaller step size. However, the accuracy of the algorithm relies on the stability of the platform when taking multiple images of Earth. Therefore, the accuracy of the estimated Earth center is directly affected by the frame rate of the FPA, the stray light condition and the spacecraft platform jitter.

Error analysis based on computational theory and simulation indicated that the algorithm is a viable approach for extended source spatial acquisition process using Sun-lit Earth images. Prototyping based on this concept is currently under development at JPL. It is expected that the approach will meet the stringent pointing requirement using multiple image scanning. Algorithms will be evaluated and compared with the two traditional algorithms based on single snapshot. Both theoretical analysis and simulations will be reported for different Earth phase images.